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Superior High Temperature Properties Available in Directionally Solidified Nickel-Base Eutectic Alloys

An alloy of the nickel-base composition containing 19.7 percent columbium, 6 percent chromium and 2.5 percent aluminum by weight, will, when directionally solidified, form an in situ composite of aligned Ni_3Cb lamellae in a strong, tough matrix of gamma (γ) solid solution with a gamma prime (γ') precipitate. This alloy has high temperature (above 1088 K (1500°F)) properties exceeding the strength of all known superalloys. It should be useful in many applications where high strength at elevated temperatures is required.

The composition is located on the liquidus surface within the Ni-Al-Cb-Cr system wherein the two solid phases, gamma (γ) and delta (δ), separate from the liquid upon freezing. The alloy solidifies at about 1522 K (2280°F) in the form of an alternating lamellae of gamma (γ) solid solution containing nickel, columbium, chromium and aluminum, and of delta (δ), the intermetallic compound Ni_3Cb. Upon further cooling, gamma prime (γ'), Ni_3Al, precipitates out of the solid solution gamma (γ) phase. By close control of the furnace temperature, by maintaining a high temperature gradient across the liquid-solid interface and controlling the rate of withdrawal, plane front biphase solidification will occur. The microstructure of alternating lamellae will be aligned parallel to the axis of withdrawal. In a high (573 K/cm (1430°F/in)) gradient furnace, withdrawal rates up to at least 7.5 cm (3 in) per hour produce a fully aligned structure in a 12.5 mm (0.5 in) diameter bar.

Test specimens were machined from 12.5 mm (0.5 in) diameter bars solidified at 3 cm/hr (1.2 in/hr) and the following properties were obtained:

Tensile Properties (in air)

Temperature K	Temperature °F	Ultimate Tensile Strength MN/m^2	Ultimate Tensile Strength psi in 1000	Yield Strength MN/m^2	Yield Strength psi in 1000	Elongation %
297	75	1250	180	1200	175	3.8
1144	1600	925	134	925	134	6.5
1272	1830	755	110	735	107	10
1366	2000	550	80	545	79	15
1477	2190	270	39	270	39	17

Creep Rupture Properties (in vacuum)

Temperature K	Temperature °F	Stress MN/m^2	Stress psi in 1000	Time to Rupture Hrs	Time to 0.2% Creep Hrs	Elongation at Failure %
1172	1650	449	65	114	43	11.6
1272	1830	276	40	24.5	5	10.4
1366	2000	138	20	74.4	16	8
1477	2190	55	8.5	115	106	6.4

The high strength at elevated temperatures is combined with excellent stability in the gamma (γ) and delta (δ) phases. The alloy resisted thermal fatigue, cracking and delamination when exposed to 3000 cycles of 2.5 minutes duration in which the temperature varied from 672 to 1394 K (750 to 1394°F). It was also virtually unaffected by 1500 hour exposure to 1120 K (1562°F) and by exposure under stress at 1477 K (2192°F) in excess of 100 hours. The density of the alloy is 8.6 g/cm^3 (0.310 lb/in^3).

The alloy exhibits an inherent resistance to oxidation and high temperature hot corrosion, but should be coated for uses above 1172 K (1650°F). Coatings for this alloy are now being developed.

The alloy is attractive as a candidate turbine blade and vane material not only because of its excellent mechanical properties and inherent oxidation resistance, but also because the γ/γ'-δ alloy system may be further improved by alloy additions. This possibility of further property improvement makes the γ/γ'-δ system of even greater interest.

A variant of this alloy exists which can be directionally solidified at higher rates. Its mechanical properties compare well with those given above; its inherent oxidation resistance, however, is decreased. The nickel base composition contains 21.75 percent columbium and 2.55 percent aluminum, by weight, but no chromium. The alloy has been solidified successfully at rates as high as 100 cm (40 in) per hour. This makes the alloy especially attractive for the production of complex parts; however, adequate protection must be provided by coatings.

(continued overleaf)

Notes:

1. These alloys are potentially useful to turbine blade and vane applications in advanced aircraft jet engines. Their temperature capabilities are such that they could be used as solid blades and vanes where air cooling is now required.
2. These alloys can also be used where high directional loads are applied to parts operating at temperatures up to 1373 K (2000°F), such as in high temperature fasteners, gripping devices, and springs.
3. Further information is available in the following report:

   NASA CR-2278 (N74-14188), Eutectic Superalloys Strengthened by δ, Ni_3Cb Lamellae and γ', Ni_3Al Precipitates

   Copies may be obtained at cost from:

   Aerospace Research Applications Center
   Indiana University
   400 East Seventh Street
   Bloomington, Indiana 47401
   Telephone: 812-337-7833
   Reference: B75-10246
4. Specific technical questions may be directed to:

   Technology Utilization Officer
   Lewis Research Center
   21000 Brookpark Road
   Cleveland, Ohio 44135
   Reference: B75-10246

Patent Status:

NASA has decided not to apply for a patent.

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